

Using spatial-temporal maps for visualization of the karst development dynamics

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Abstract. There is a problem of visualization dynamics of karst processes during territory monitoring. For this can be used geographic information system. All information on existing forms of karst processes can be connected to the map based on the coordinates. But there is a need to include into GIS the information about the dynamics of the karst processes. There is a big problem to solve this task in traditional GIS. Development of karst processes has features that affect their visualization in GIS: the shape and the state of karst objects may change; existing karst forms can be replaced with new objects; the frequency of state changes and appearance of new objects is small; cartographic basis (map) may change as a result of the impact of natural phenomena and human activities. To solve the problem can be used spatial-temporal GIS. In paper the basic features of the karst processes development that affect their storage and display on maps are given. The questions of organization of karst processes dynamics visualization on the basis of spatial-temporal maps are presented. Practical issues of linking the objects in map, display of them geometry, determine temporal boundaries of objects existence are describes.

Keywords: karst, spatial-temporal map, visualization.

1. Introduction

Karst processes have a significant impact on the safety of civil and industrial facilities. Actual tasks are objective assessment of karst hazard of a particular territory and reducing to a minimum the probability of catastrophes on newly constructed buildings caused by the development of karst processes.

During the implementation of karst processes observation system in the area of the proposed construction of Nizhny Novgorod NPP in the village Monakovo arose the problem of the linking karst forms data to cartographic basis and its visualization [1].

With the advent of geographic information systems (GIS) there was new direction - the computer cartography. It has been actively used in different spheres of activity. Unlike paper maps, the use of computer technology allows users to select the desired information and produce its visualization in a user friendly manner. This may change the level of detail - enables or disables display of various layers of maps (topography, water bodies, roads, buildings, etc.), carried out generalization when zooming. In addition, GIS allow interactive display of information with support for interacting with objects on the map (for example, information about the selected object). All this inspired us to implement linking karst processes observing system to GIS.

At the initial stage of the project there was almost no difficulties - all information on existing forms of karst processes was linked to the area map based on the coordinates. But later it became necessary to make information on the dynamics of development of karst processes. For example, in early 2014 formed a new sinkhole in village Chud that has absorbed already existing sinkhole. There is a problem: what to do with information on the sinkhole - to link it to new sinkhole, remove or remain unchanged? A similar problem arose after filling with water several karst forms formation and in their place a small pond.

Of course, to display the current status sufficient to store information about currently available forms of karst. In this case, the mapping of the previous states is not required. On the other hand, to obtain a full picture of the development of karst processes necessary to have data about their dynamics. This gives rise to new task: to visualize not only the current state of karst processes, but also the previous state (getting maps for a given timestamp, for example, one year ago, 10 years ago, etc.). In other words, there is a need to compile retrospective (time) maps.

Purpose of work - consider the practical aspects of data linking of karst processes observing system to the geographic information system for the visualization of their development.

2. Main features of karst processes observations

In the observation system for karst processes for each of karst forms there are one or more the descriptions (observations). Each observation can be given as a full or partial (only the important characteristics or changes) description. For a number of observations can be traced to the development of karst processes and the changes (evolution) karst forms.

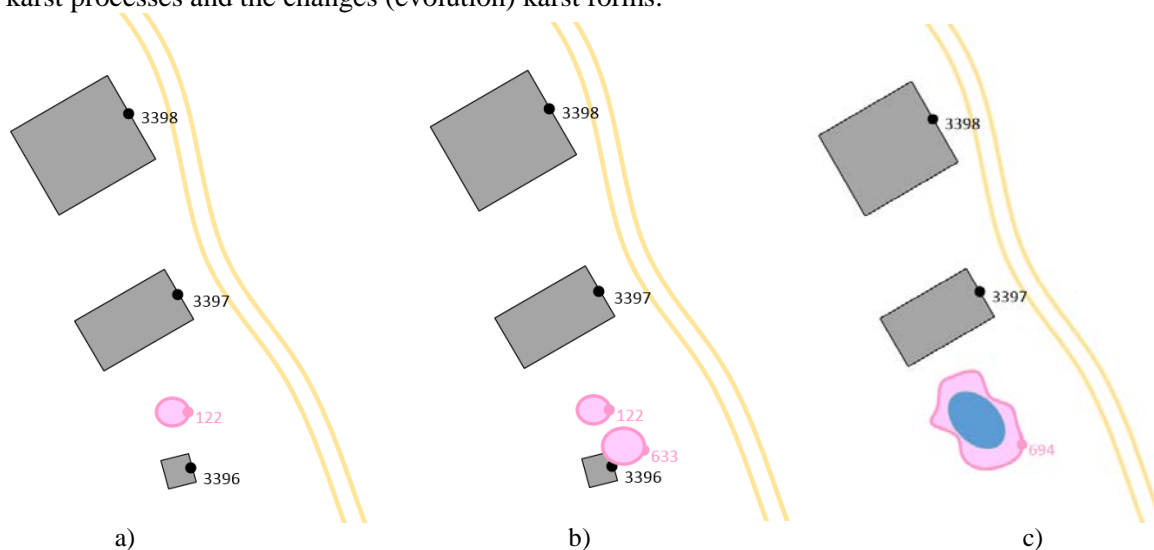


Figure 1. An example of the evolution of karst forms on the map: a – One karst form, b – The appearance of the second karst forms with the partial destruction of the object, c – Union of karst forms in a partially filled with water.

Let's consider the example of the evolution of karst forms (see. fig. 1). At the initial time there is a sinkhole №122 (Fig. 1a), which is located between a residential house and a bath. During the development of karst processes formation a new karst form №633 (sinkhole), affecting existing object №3396 (bath), and causing its partial destruction (Fig. 1b). During the further lowering of the surface object №122 and №633 combined into a single complex objects №694, which is partially filled with water (Fig. 1c). As can be seen, in the latter case there was a change of the cartographic basis - disappeared (was disassembled) object number 3396 (Bath).

Let's consider the features of karst processes, affecting their visualization in GIS:

- form and the state of observation objects (karst forms) can be changed;
- the position of karst forms in space remains constant (except for changing their geometry);

- existing karst forms can be replaced with new objects (such as merging several sinkholes into a single object);
- the frequency of changes in the state and the emergence of new objects is small;
- cartographic base may vary as a result of the impact of natural phenomena and human activities.



Figure 2. Set of satellite images of territory taken at different times.

3. Requirements to temporal maps

Let us consider the basic requirements that must be satisfied visualization system of observational data on the development of karst processes:

- the system should allow to reflect changes of the territory in time,
- the system should allow to reflect changes in the state and geometry of objects,
- there is no need to display moving objects in space,
- update rate corresponds to the frequency of observations (usually once a year, for a particularly dynamic phenomena - up to several times a month),
- cartographic base must be updated periodically to update information on the area,
- task of visualization information of karst processes development should be in addition to the already existing system of observation and analysis.

Because the task of visualizing of karst processes development is in addition to the already existing system of observation and analysis, the preference in the organization of the storage system must be assigned to it usability with observations rather than ease of use together with the GIS.

4. Approaches to building spatial-temporal maps

There are two basic approaches to create a spatial-temporal maps:

- Creating a set of spatial-temporal maps showing the status of research in specific periods of time (e.g., once a month, once a year, etc.)
- Automatically generating maps based on observation data (including animation dynamic changes).

The first variant is quite laborious. It requires the involvement of specialists to create the next map. Due to this, the process of creating maps is moderated and controlled to eliminate human error. Moreover, in the preparation of each new map it is possible to use the updated cartographic base (map of area).

The second option does not require specialists to generate a maps - it happens automatically. As a result - errors may occur. However, the variant of automatic generation of maps is more attractive.

There are quite a number of works devoted to the creation and use of spatial-temporal maps. Such maps are used to monitor traffic, road load, display the current status and weather forecasts, the spread of pollution, etc. There are solutions for displaying dynamics of various processes, including real-time. For this purpose special Spatial-Temporal GIS and Temporal GIS.

In [2] discussed questions retrospective (temporal) presentation information in a GIS. A model of time in cartography and variants for presentation of spatial-temporal data using models of space-time cube, sequential images, the base of states with changes and the space-time combination.

In [3] given the basic model for the implementation of temporal GIS: models based on the position of objects, on the objects or their features, on the time, event model, process-oriented models, causal models.

Each object can be described as a triplet (o_i, s_i, t_i) , where o_i – object features, s_i - the spatial position of the object, t_i - timestamp when o_i exists in s_i (see. fig. 3) [3].

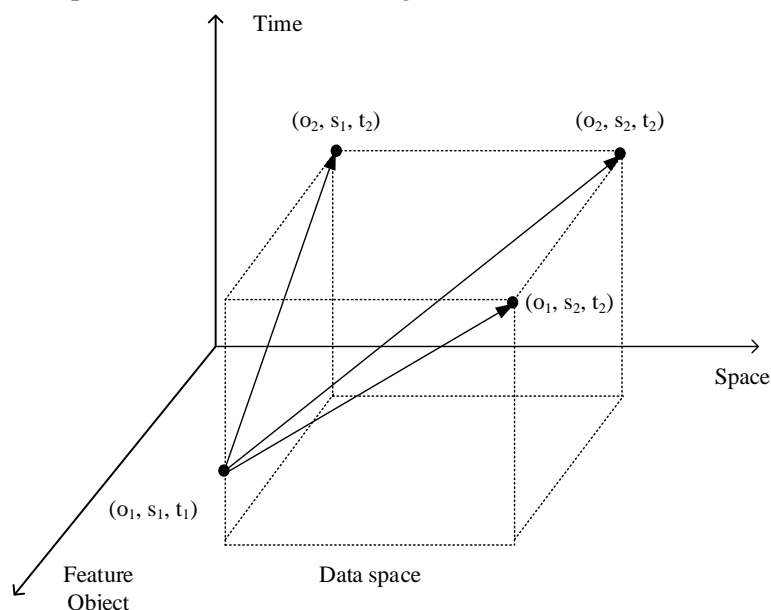


Figure 3. 3D data space.

Models based on the object's position, considering moving along the axis of “space”. In this case, the model is a set of parallel planes “Feature-Time” $\{(o, s_j, t)\}$, where $1 \leq j \leq n$ [2].

Models based on the objects or features considering moving along the axis of “Feature”, and is a set of parallel planes, “Space-Time” $\{(o_i, s, t)\}$, where $1 \leq i \leq m$ [4, 5, 6].

The models based on time, make temporary snapshots of reality (of planes “Space-Feature”) $\{(o, s, t_k)\}$, where $1 \leq k \leq l$ [3].

In the event model, state transition represents an event. Events can be represented as lines connecting the two states in the data space [7, 8].

In the a process-oriented models are considered occurring processes, such as changing a single object, the functional relationship between objects or modify the spatial structure associated with some aspects [9].

Questions of modelling and management of spatial and temporal data considered in papers [10, 11]. Thus, there are a number of solutions in the field of presentation space-time (retrospective) information in a GIS. The use of a decision is largely due to the set in each case the task.

5. Presentation of data for visualization

5.1. Data model.

In accordance with the task, it is needed only display the time information, i.e. creation of retrospective maps. For this reason, the basic information for visualization to be objects (karst) and their status (geometry, water availability, etc.).

5.2. Spatial reference object.

As a basis for spatial reference karst forms the basis used to map GPS coordinates of objects. Because objects do not move in space, their coordinates on the axis "space" remain constant.

5.3. Object geometry.

Manifestations of karst processes (sinkhole) are closed, often circular, shape. For this reason, the map can be presented either in the form of an ellipse or a closed polyline. In the first case it is sufficient to store the coordinates of the ellipse center and the radius the major and minor semi-axes. Additionally, it may indicate the angle of rotation of the axes of the ellipse. In the second case, a sequence of pairs of coordinates storage defining the contours of the object. In this last pair of coordinates must be equal to the first.

5.4. Evaluation time presence of the object.

Since karst forms can occur at different times, there is the problem of determining time slots, where a form will be displayed on the map (the axis of "Time"). To determine the initial interval may use information about the time of occurrence the karst forms or data first describe it. The time of occurrence can not always be determined: sinkholes are formed slowly, and the old sinkholes can not be properly described. In this case, the first time is used to describe an object.

The upper boundary of the time display object is set only if the status of an object indicates that it has ceased to exist (moved to another facility, or has been removed). In the this case, the date of the last of the description (in which the status was changed and the object) and read by the upper boundary of the time display.

5.5. Feature of the object

To determine the features of karst forms (axis "Feature") used observations. Specific features of the objects selected from a set of data represented in each observation. Karst object can change its state. For example, sinkholes can be filled with water, turn into swamp or dry.

Since observations may be incomplete and often describe only certain changes to detect feature changes necessary to analyze not only current, but previous observations of objects. Status change has s_i if $s_i \neq s_j$, where $s_j \neq 0$ (a set value) and $i > j$. Since not all states can be described in the observations, adopted a set of default conditions (such as lack of water in karst, the lack of vegetation, etc.).

5.6. Object status.

The development of karst-suffusion processes, objects can be combined with each other. With active business karst may disappear (e.g., falling sinkholes at the earthworks). For this reason, it is necessary the introduction of the status of the object. The default status for any object – "object exists". When combined with other objects are labelled as "object merged", the transformation of the object (for example, the conversion of the sinkhole to water bodies), set the status "object is transformed". With the disappearance of the object status is set to "object does not exist".

6. Practical implementation

On the basis of presented approaches has been implemented visualization module of karst processes observations in a GIS. As a basis for implementation, Open Source Geographic Information System QGIS was used.

By default, the visualization of the current status of the map with karst, confirmed in the most recent observations. The user can select the desired time stamp and the module calculates the existence of objects. All objects, while the presence of (being) which overlaps with the selected time stamp, is automatically drawn in separate dynamic layers (karst holes, sinkholes, water bodies, etc.).

The results of the practical implementation of the visualization system on the example of studies of particular area in Nizhny Novgorod region [12]. Implementation of a system for the Nizhny Novgorod region has allowed us to see areas where karst processes are actively developing at present time. In addition, we were able to see the areas in which there are many karst forms, but they formed a long time ago and is currently active karst processes is not observed.

7. Conclusions

The proposed solutions connect the data observation system for karst processes to geographic information system and solve the problem of visualizing their development. Due to the fact that the display of karst on the map is carried out on a given timestamp automatically according to the observations, it is possible to observe the dynamics of development of karst processes in user-defined time frame.

Visualization of karst processes in time allows anew look at the problem of studies of karst territories. With this solution, the user can see the area as it was in the past. Without the use of a spatial-temporal GIS to user available maps showing only the current status of the territory.

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